

“The Origin of the Gases evolved on heating Mineral Substances, Meteorites, &c.” By MORRIS W. TRAVERS, D.Sc. Communicated by Professor W. RAMSAY, F.R.S. Received November 14,—Read November 24, 1898.

The study of the gases evolved on heating mineral substances has been made the subject of a number of investigations, and the results have formed a basis for speculations as to the origin and history of these substances.

In a paper entitled “The Gases enclosed in Crystalline Rocks and Minerals,”* Professor Tilden has suggested a theory to account for the evolution of gases by mineral substances under the influence of heat. He considers that the gases, which are given off on heating certain rocks and minerals, are actually present in those substances in the gaseous state, enclosed in small cavities under high pressure. To account for their presence in these cavities he makes the suggestion, “that the rock crystallised in an atmosphere rich in carbon dioxide and steam, which had been, or were at the time, in contact with some easily oxidisable substance, at a moderately high temperature. Of the substances capable of so acting, carbon, a metal, or the protoxide of a metal, present themselves as most probable.”

Beyond the fact that minerals give off gases when heated, there is, except in the case of carbon dioxide, no direct experimental evidence to show that these substances really contain the gases in the free state. In many cases no cavities can be seen in thin sections of the mineral, and as a mineral yields about the same quantity of gas when ground to a fine powder as when it is only broken into small pieces, the cavities must be assumed to be very minute if they exist at all. I do not contend that it is impossible for a rock to contain considerable quantities of gases enclosed in cavities, but I propose to prove experimentally, that at least in some cases where a mineral or rock yields gases other than carbon dioxide on heating, those gases are produced during ignition, by the interaction of its non-gaseous constituents. I shall first consider the formation of carbon monoxide and hydrogen from minerals and rocks which contain as active constituents only water, carbon dioxide, and ferrous oxide.

A glance through the results of the analyses of some such substances, and of the gases evolved by heating them, will show that the quantity of hydrogen and carbon monoxide produced bears a certain relation to the quantity of ferrous oxide and to the quantity of water given off on heating the substance. In the following table the quantities of ferrous oxide and water are expressed in terms of weight *per cent.*; the gases in cubic centimetres per gram of mineral.

* ‘Roy. Soc. Proc.,’ vol. 60, p. 453.

Mineral.	Locality.	FeO.	H ₂ O.	H ₂ .	CO.	CO ₂ .
Chlorite.....	Zoptan, Moravia	10·6	4·6	2·180	0·494	0·123
Serpentine ¹ ...	Zermatt	2·7	9·5	0·800	none	none
Gabbro	Isle of Skye	6·1	1·5	0·490	none	none
Mica	Westchester, Pennsylvania	1·4	0·13	0·08		0·150
Foliated talc ² ...	Greiner, Tyrol ...	0·4	4·5		0·04	0·070
Felspar ³	Peterhead.....	2·1	1·00		0·214	1·201

¹ Analysis by Miss E. Aston, 'Quart. Jour. Geol. Soc.,' 1896, vol. 52, p. 456.

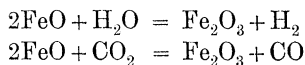
² The talc lost only 0·06 per cent. of water when heated in the hard glass tube, remainder came off at a very bright red heat.

³ The felspar contained free iron.

The estimation of the ferrous iron was conducted in the following manner. The sulphuric acid (30 per cent.), previously boiled and cooled in a corked flask, was poured into the bottom of a thick-walled glass tube. The mineral was weighed out into a small test-tube with a glass rod sealed to the bottom of it to support it above the sulphuric acid in the large tube during exhaustion. The tube was drawn out at the end as in fig. 1, attached to a Töpler pump by a rubber tube, exhausted, and sealed at the capillary. After heating to 170°—till the mineral was entirely decomposed—the tube was again attached to the pump as in fig. 2, the point of the capillary was broken inside the rubber tube and the gas contained in it was pumped out and analysed. The tube was afterwards cut open and the ferrous sulphate was estimated by titration with a solution of potassium permanganate. In the case of the mica it was necessary to use strong sulphuric acid to decompose the mineral.

In general, the gas contained in the sealed tube consisted only of carbon dioxide. In the case of the felspar from Peterhead granite, and of certain helium-yielding minerals, the gas also contained hydrogen. I shall deal with these minerals separately.

That the minerals, which on heating give hydrogen and carbon monoxide, give neither of these gases when decomposed by means of dilute sulphuric acid, is almost sufficient evidence to show that the gases are not present in the minerals in a free state, *either occluded*, or enclosed in cavities. That the amount of hydrogen and carbon monoxide produced by heating a mineral is, as I have shown, proportional to the amount of ferrous oxide, water, and carbon dioxide present in it, may be taken as evidence that the gases are produced by the interaction of these substances when the mineral is heated, according to the equations :—



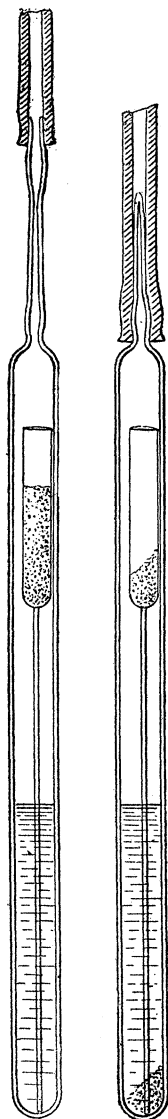


FIG. 1.

FIG. 2.

If this is the case, the mineral, after ignition *in vacuo*, should contain less ferrous oxide than it did originally; the difference between the quantities of ferrous oxide before and after heating should be equivalent to the hydrogen and carbon monoxide evolved; and these may be calculated from the equations written above.

One c.c. of hydrogen or carbon monoxide is equivalent to 0.006428 gram of ferrous oxide.

In order to prove this experimentally, I selected a chlorite from Zoptan in Moravia. This mineral contained 10.60 per cent. of ferrous oxide, 4.79 per cent. of water, and consequently gave a considerable quantity of hydrogen on heating. It was also quite free from sulphides, which seriously interfere with the accurate estimation of ferrous oxide.

A weighed quantity, about 10 grams, of the chlorite was heated in a hard glass tube till it ceased to give any gas. The gas was collected and analysed, and the loss of weight of the mineral was determined, by weighing the hard glass tube before and after heating.

Analysis of gas expressed in cubic centimetres per gram—

CO ₂		0.123
CO		0.094
H ₂		2.180

Loss of weight on heating, 4.79 per cent.

The mineral was allowed to cool *in vacuo* to prevent the oxidation of the ferrous oxide. The ferrous oxide was estimated in a sample of the mineral before and after heating.

Ferrous oxide in mineral before heating—

(a) 10.62 per cent.; (b) 10.60 per cent.;
mean, 10.61 per cent.

Ferrous oxide in mineral after heating—

(a) 9.70 per cent.; (b) 9.61 per cent.;
mean, 9.65 per cent.

But since the mineral lost weight to the extent of 4.79 per cent. on heating, a correction must be applied.

Ferrous oxide in mineral after heating, corrected for loss of weight of mineral	9.18 per cent.
Difference in amount of ferrous oxide present in mineral before and after heating	1.43 ,,

The amount of ferrous oxide oxidised to ferric oxide can also be calculated from the quantities of hydrogen and carbon monoxide collected.

2.180 c.c. per gram of hydrogen is equivalent to	1.401 per cent. of FeO
0.094 c.c. per gram of carbon monoxide is equivalent to	0.057 ,, ,,
Total.....	1.458 ,, ,,

This number agrees very closely with that already obtained.

The application of this method of investigation is very limited, as it is difficult to obtain minerals which are quite free from sulphides and carbonaceous matter, and which at the same time give on heating a sufficient quantity of carbon monoxide and hydrogen. Other specimens of chlorite gave large quantities of hydrogen on heating, but they were found to contain sulphides.

The minerals and rocks, which had been investigated up to this point, had all been of igneous origin. At Professor Bonney's suggestion, I next proceeded to determine whether minerals of aqueous origin, containing ferrous oxide, water, and carbonates, would give hydrogen and carbon monoxide on heating. Professor Bonney kindly obtained for me a specimen of chalk marl, rich in glauconite, from the Cambridge beds.

The glauconite was freed from chalk as far as possible by washing with dilute hydrochloric acid. The residue, seen under the microscope, appeared to consist of foraminiferous casts, with adhering grains of glauconite. The sample taken for the experiment contained 1.33 per cent. of ferrous oxide, 15 per cent. of water, and 13.7 per cent. of calcium phosphate.

Heated in a hard glass tube to a dull red heat for some time, only 5.7 per cent. of the water was given off with a considerable quantity of gas, which was found on analysis to have the following composition:—

CO ₂	4.518 c.c. per gram.
H ₂	3.128 ,,
CO	0.083 ,,
CH ₄ , &c.	0.204 ,,

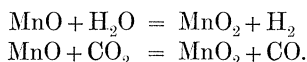
On heating to a bright red heat in the flame of a Bunsen burner, the remaining water and more gas was given off:—

CO ₂	13·38 c.c. per gram.
H ₂ , &c.	0·25 ,,

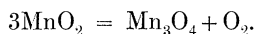
The greater part of the hydrogen and hydrocarbons is probably produced by the breaking down of organic matter in the mineral. This organic matter may be due to infiltration from the surface, but, considering the treatment the mineral had received, it is more probably contained in the foraminiferous casts, the decomposition products of their original occupants.

The presence of manganous oxide in minerals appears also to favour the production of hydrogen and carbon dioxide; indeed, it has long been known, that when moist manganous carbonate is heated, these gases are always produced along with carbon dioxide.

The first reactions which take place when the mineral is heated, may be expressed by the equations:—



But it was found that when cerite, a mineral which contains a considerable quantity of manganous carbonate was heated, the gas contained not only hydrogen, but oxygen, the product of a reaction taking place at a somewhat higher temperature:—

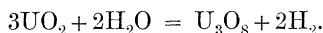


Analysis of the gas obtained by heating finely powdered cerite gave the following results:—

CO ₂	15·0 (about) c.c. per gram.
CO	1·554 ,,
H ₂	3·905 ,,
O ₂	0·406 ,,

A cobalt ore containing only the higher oxides of manganese gave about 10 c.c. of oxygen per gram of minerals.*

Yttrotantalite, samarskite, &c., containing lower oxides of uranium, also give small quantities of hydrogen when heated. The hydrogen may be produced according to the equation:—



The quantity of hydrogen is not, however, very large.

Minerals containing sulphides usually give a mixture of hydrogen, sulphuretted hydrogen, and sulphur vapour when heated. The quantity of gas is often very large, but the reaction is too complicated for direct investigation. It is probable that the sulphides react with water

* 'Roy. Soc. Proc.,' vol. 60, p. 444.

forming sulphuretted hydrogen, which at the temperature of the reaction is decomposed into sulphur and hydrogen.

It is known that certain crystalline minerals contain liquid hydrocarbons enclosed in cavities. It is also possible that the methane, and other hydrocarbons sometimes present in the gases obtained by heating mineral substances, may be produced by the destructive distillation of bituminous matter infiltrated into it, or from vegetable matter, particularly if the specimen has been long exposed on the surface.

Nitrogen I have only rarely obtained by heating minerals. Malacone* yields it in larger quantity, compared with the total quantity of gas evolved, than any other mineral which I have examined, but even in that particular case only a very small quantity of the gas is obtained. It is possible that a finely powdered mineral may on standing condense air on its surface. Dr. G. McGowan tells me that when a sample of china clay was heated in a current of hydrogen a small quantity of ammonia was given off. Certain bituminous shales, in which the organic matter is certainly of animal origin, are known to contain large quantities of ammonium salts; the gases evolved under the influence of heat would certainly contain nitrogen. Nitrogen and its oxides might also be the product of the interaction at a high temperature of nitrates infiltrated into the rock, and silica. That Davy obtained nitrogen from quartz is highly improbable. It is more likely that the gas was introduced accidentally in the course of the experiment.

I stated earlier in this paper that the felspar from Peterhead granite exhibited certain peculiarities, and that I should describe it separately. The granite consisted of very large crystals of quartz and felspar with a comparatively small quantity of mica of a dark colour. On heating, a mixture of carbon dioxide, carbon monoxide, and hydrogen was given off.

In order to ascertain whether these gases were derived from each of the minerals, or whether any particular one gave more gas on heating than the others, I crushed a large quantity of the granite in an iron mortar and picked out the constituents, separating them from one another as far as possible. The mica was easily obtained quite pure, but the quartz and felspar could not without very great trouble be separated from one another; in fact, the felspar always contained a considerable quantity of the latter mineral.

By heating weighed quantities of the component minerals to red heat in hard glass tubes, and collecting and analysing the gases, the following results were obtained. The results are expressed in cubic centimetres of gas per gram of mineral:—

	Quartz.	Mica.	Felspar.
Carbon dioxide	0.225	none	0.172
Carbon monoxide	0.074 {	none	0.059
Hydrogen		0.164	0.218

* 'Roy. Soc. Proc.,' 1897, vol. 60, p. 444.

These results show that the mica and felspar are responsible for nearly the whole of the hydrogen, while the greater part of the carbon dioxide is derived from the quartz. The carbon dioxide is probably present in cavities in the quartz, but if the hydrogen were also present in cavities, one would expect that it would be also obtained in greatest quantity from the quartz, the only mineral of the three which has no cleavage; one would not certainly expect to obtain it from the mica.

As the felspar gave off gas in the cold when treated with dilute sulphuric acid, a weighed quantity of the mineral was placed in a thick-walled tube, with a second tube containing 50 per cent. sulphuric acid. The tube was drawn to a point, exhausted, and sealed in the manner already described. After heating for twenty-four hours to 170° the gas was pumped out and analysed, and the ferrous sulphate in the solution was determined.

The following results were obtained from two samples of felspar from different parts of the same block of granite. The quantities of gas are expressed in cubic centimetres per gram:—

Ferrous oxide in solution	(a) 4.02 p.c.	(b) 2.05 p.c.
Hydrogen with trace of hydrocarbon	3.50 "	1.99 "
Carbon dioxide	0.20 "	0.90 "

From these results I was led to suppose that the felspar contained both free iron and ferrous oxide, since if we calculate the amount of iron which would be equivalent to the hydrogen evolved, we find that expressed in terms of ferrous oxide,

3.50 c.c. of hydrogen per gram	=	2.25 per cent. of ferrous oxide.
1.99 " "	=	1.23 " "

Quantities which are considerably less than the quantity of ferrous oxide found by titration. On the other hand, it is possible that some of the hydrogen is taken up by the ferric compounds present, lessening the yield of hydrogen, and increasing the quantity of ferrous sulphate in the solution.

There is, unfortunately, no accurate method of estimating the free iron in minerals. The copper method apparently fails in the presence of hydrated ferric oxide, on account of the secondary reactions which take place between that compound and copper sulphate, and subsequently between the ferric sulphate and precipitated copper.

In order to prove that a considerable amount of free iron was present in the felspar, two weighed quantities of felspar from the same sample were heated with 50 per cent. sulphuric acid and 96 per cent. acid respectively. The gases were subsequently pumped out of the tubes and analysed, and the ferrous sulphate was estimated in the liquid.

The following results were obtained :—

(a) With strong sulphuric acid, carbon dioxide		
and sulphur dioxide	1.26	c.c. per gram.
Hydrogen and trace of hydrocarbons.....	0.49	„
Total	1.75	„
Ferrous oxide	2.07	per cent.
(b) With 50 per cent. sulphuric acid, carbon dioxide		0.23
Hydrogen and trace of hydrocarbons.....	1.64	„
Total	1.87	„
Ferrous oxide	2.26	per cent.

These figures indicate that the sulphur dioxide and hydrogen produced by the action of the strong acid is just equivalent to the hydrogen produced by the dilute acid, indicating that the felspar contains metallic iron, which is probably the source of the whole of the hydrogen evolved when the mineral is treated with acid. The hydrogen and carbon monoxide given off on heating the felspar are produced by the action of water and carbon dioxide on ferrous oxide and metallic iron present in the mineral.

Both the gas obtained by heating the felspar and gases obtained from the sealed tube experiments contained traces of hydrocarbon. This may be accounted for on the assumption that the free iron in the felspar contains a small quantity of carbide.

Meteorites.

It has long been known that considerable quantities of gas are evolved when meteorites are heated *in vacuo*. The gas usually consists of hydrogen, carbon monoxide, carbon dioxide, and hydrocarbons, in varying proportions, and attempts have been made to draw conclusion as to the origin of different meteorites from the results of analysis of the gases obtained by heating them. These speculations are based upon the supposition that the gases evolved on heating are present as such in the meteorite, occluded from the atmosphere in which it previously existed.

Beyond the gases already mentioned, the results of many observers appear to show that nitrogen is also invariably present. Among those that I have examined the gas evolved on heating contained, in no single instance, a trace of nitrogen.* Graham† found as much as 10 per cent. of nitrogen in the gas from the Lenarto meteorite, and

* 'Roy. Soc. Proc.,' 1897, vol. 60, p. 442.

† 'Roy. Soc. Proc.,' 1867, vol. 15, p. 502.

Mallett* found 10 per cent. of nitrogen in the gas from a meteorite from Augusta Co., Virginia. Wright† examined a large number of meteorites, and found that in almost every case the gas contained nitrogen. In this case, however, the presence of nitrogen can easily be accounted for, as no particular precautions were taken with regard to the thorough exhaustion of the apparatus employed. A Sprengel pump was used, "which was kept running till the air was thoroughly removed, *as could be seen by the gauge.*" Dewar‡ found nitrogen, in quantities not exceeding 4 per cent. of the total gas, in the gases from samples of meteorites and graphite.

In one single case a meteorite has been found to yield a trace of helium on heating.§

With regard to the carbon dioxide and combustible gases, it is difficult to obtain direct evidence as to their origin. In the case of meteorites containing bituminous matter and carbonaceous nodules, the evolution of these gases may be attributed to the destructive distillation of their constituents. Meteorites of the stony variety appear to evolve more carbon dioxide and hydrocarbons, and less hydrogen and carbon monoxide, than those which are of a metallic nature. Several specimens of stony meteorites have been carefully examined by Wright and Dewar with the following results:—

Wright (*loc. cit.*) found that in the case of a stony meteorite from Iowa Co., Iowa, the carbon dioxide was given off at a very low temperature. The following table shows the composition of the gas given off at different temperatures:—

	At 100°.	At 250°.	Below red heat.	Dull red heat.	Full red heat.
CO ₂	95·46	92·32	42·27	35·82	5·56
CO	0·00	1·82	5·11	0·49	0·00
H ₂	4·54	5·86	48·06	58·51	87·53
N ₂	0·00	0·00	4·56	5·18	6·91

The meteorite lost about 10 per cent. of its weight of water on heating. The water was allowed to collect in the apparatus, and as no drying reagent was used, it is easy to account for the presence of hydrogen in the gas. The carbon dioxide may have been present as an unstable hydrated carbonate, or in the state of occlusion in the pores of the substance.

Dewar (*loc. cit.*) showed that a meteorite of a similar nature was capable of reabsorbing water and carbon dioxide after the gases had been removed by heating *in vacuo*. The following results were obtained:—

* 'Roy. Soc. Proc.,' 1872, vol. 20, p. 365.

† 'Amer. J. Sci.,' [3], vol. 9, pp. 294 and 459; vol. 10, p. 44; vol. 11, p. 254.

‡ 'Roy. Inst. Proc.,' 1886, p. 545.

§ 'Nature,' 1896.

	Gas in volumes of meteorite.	CO ₂ .	CO.	H ₂ .	N ₂ .
After 24 hours	0·61	54·0	—	42·4	3·6
After 6 days more ...	2·47	47·0	5·0	47·0	1·0
After 8 days more ...	0·63	96·1	2·0	1·5	—

The quantity of water reabsorbed after the second heating was very small, and it is interesting to note that the quantity of hydrogen evolved during the subsequent heating was also very small. From this it would appear that the hydrogen was produced directly from the water. There is no evidence to show whether the carbon dioxide entered into combination with some constituent of the meteorite, or not.

Meteorites of the second class usually consist chiefly of metallic iron, nickel, &c., with small quantities of crystalline minerals, such as olivine. The presence of these minerals, which are usually hydrated silicates containing ferrous oxide, might in themselves account for the formation of hydrogen. The carbon monoxide might be produced by the interaction of carbon dioxide, the product of decomposition of a carbonate, with the metallic iron. The small quantities of hydrocarbon, which are also present in the gas, and which appear to belong to the saturated series, might be produced by the action of water, which is invariably present, upon metallic carbides. The changes which take place are probably of a complicated nature.

In order to ascertain whether a sample of meteoric iron actually contained occluded or enclosed gases, the following experiment was performed. A piece of meteoric iron was cut into fine shavings, which were carefully cleaned. The metal was divided into two portions; one part was heated in a sealed tube with copper sulphate and water, in the manner already described, the other was heated *in vacuo*. The gases evolved were in each case collected and analysed.

	By action of heat.	Copper sulphate experiment.
Hydrogen	0·322 c.c. per gram	} 0·014
Carbon monoxide and hydrocarbons...	0·164 " "	
Carbon dioxide	2·222	0·739

The trace of hydrogen which was produced during the copper sulphate experiment may well be attributed to secondary relations between the metal and the salts in solution.

It would appear then that the gases produced by the action of heat upon meteorites are not present as such, but are the products of decomposition of their non-gaseous constituents. It is therefore impossible to draw conclusions as to the former history of a meteorite from the nature of the gases which it gives on heating.

Helium and Argon.

With regard to the state in which helium is present in the minerals from which it is obtained by the action of heat, there is at present no conclusive evidence. It must be present under one of three conditions :—

- I. In combination with some constituent of the mineral.
- II. Occluded ; or in solution in the mineral.
- III. Enclosed in cavities under pressure.

Microscopic examination of the minerals, from which helium has been derived, has failed to reveal the presence of cavities, and, indeed, if we assume that cavities exist, and that they contain all the helium present in the mineral, we have to make further assumptions to explain why the helium escapes when the mineral is heated, although in most cases no disintegration takes place. It seems improbable that the helium is present in the state of solid solution or occlusion, a condition of which we yet know little, for unless we assume that the rate of diffusion of the helium through the mineral in which it is dissolved is infinitely small, the gas should long ago have escaped into the atmosphere. Further, it is probable that the supposed cases of solution of gases, like hydrogen, in solids such as platinum, palladium, &c., are really cases of chemical combination, as has recently been proved by the researches of Ramsay, Mond, and Shields, and even in meteoric iron it is improbable that the hydrogen is not present as such, but is the product of secondary reactions. Indeed, in the state of our knowledge at present it is impossible to draw a distinction between occlusion and chemical combination.

We are, therefore, forced to the conclusion that helium is present in the minerals in the state of combination with one of its constituents. It may be well to review such positive evidence as exists in favour of such a supposition.

In the first place the gas is not found generally dispersed among crystalline mineral substances, but seems only associated with certain elements, uranium, yttrium, &c., in minerals which are invariably vein products.

It has been pointed out by Professor Ramsay and the author,* that in certain cases the evolution of helium from the mineral is accompanied by a considerable evolution of heat, and in one case by a considerable decrease in density. This matter has been dealt with fully in the paper (*loc. cit.*), and is considered as evidence in favour of chemical combination. Julius Thomsen† has confirmed this observation.

* 'Roy. Soc. Proc.,' vol. 62, p. 325.

† 'Zeit. Phys. Chem.,' vol. 25, p. 112.

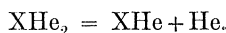
A series of experiments were undertaken to determine the conditions under which the minerals gave off helium. It was found that from clèveite helium was evolved, but very slowly, at the temperature of boiling quinoline, and somewhat faster at the temperature of boiling sulphur. At a bright red heat a considerable quantity of helium was obtained, but in no case did the mineral lose the whole of its helium under the influence of heat alone.

By heating clèveite to redness for some hours a mixture of helium, hydrogen, carbon dioxide, and carbon monoxide was obtained; the gas came off readily at first, and appeared finally to cease altogether.

A quantity of the same sample was completely decomposed by means of sulphuric acid (30 per cent.) in an exhausted sealed tube. The results are given below:—

	By heating the mineral.	By action of sulphuric acid.
He	1·487 c.c. per gram.	3·201 per cent. per gram.
H ₂	0·367 ,,	0·333 ,,
CO ₂	2·298 ,,	

It will be noticed that only half the helium is given off on heating the mineral; this makes it appear probable that if the helium is present in the mineral originally in a state of binary combination the decomposition takes place according to the equation:—



A specimen of fergusonite was also examined, but the results were not altogether satisfactory, as it was found to be practically impossible to completely decompose the mineral by the action of 30 per cent. sulphuric acid; strong sulphuric acid appeared to be still more inactive. When fused with acid potassium sulphate a larger yield of helium was obtained but the mineral was not completely decomposed. The following figures indicate that about half the helium contained in the mineral is liberated under the influence of heat.

	By action of heat on mineral.	By 30 per cent. sulphuric acid	Fusion with acid sulphate.
He ...	1·041 c.c. per gram.	1·434 c.c. per gram.	1·813 c.c. per gram.
H ₂ ...	0·231 ,,	0·163 ,,	
CO, &c.	0·326 ,,		

It is somewhat significant that both clèveite and fergusonite yield hydrogen when decomposed by sulphuric acid. If the helium were present in combination with a metal it would eventually be liberated as a hydride. It is probable that the hydride would be a very unstable compound and would decompose at the moment of formation. Part of the hydrogen would probably be taken up by the ferric and uranic compounds, and part would escape in the gaseous state. A similar

reaction would take place between sulphuric acid, and an iodide, in the presence of a reducible substance, at a higher temperature.

Conclusions.

It would appear that the only evidence on which the assumption that gases of a permanent character, such as hydrogen, carbon monoxide, nitrogen, helium, and argon, exist in the free state in the mineral substances from which they are evolved on heating, rests on certain observations with regard to the cavities which can sometimes be detected by microscopic examination.

The cavities may be either apparently empty or they may contain liquid, and when the mineral is warmed the liquid disappears at a temperature which is a few degrees below the critical point of carbon dioxide or of some hydrocarbon. The fact that the critical temperature of the liquid is a little below the point corresponding to carbon dioxide, in the case of a mineral containing that substance, is not, however, of very great significance as pointing to the presence of a permanent gas. A small quantity of methane would produce the same result.*

Further, although it can be shown that *compact* minerals do enclose carbon dioxide and hydrocarbons, gases which can easily be liquefied, the analogy cannot be extended to gases such as hydrogen and helium in connection with minerals like chlorite, mica, and clèveite, which exhibit many cleavages.

On the other hand, there is, as I have endeavoured to show, a considerable amount of evidence in favour of the theory which I have put forward:—That in the *majority of cases* where a mineral substance evolves gas under the influence of heat, the gas is the product of the decomposition or interaction of its *non-gaseous* constituents at the moment of the experiment. The results of such experiments cannot, therefore, serve as basis for speculation as to origin and history of the substances in question.

“The Electrical Conductivity and Luminosity of Flames containing Vaporised Salts,” By ARTHUR SMITHELLS, H. M. DAWSON, and H. A. WILSON. Communicated by Sir H. E. ROSCOE, F.R.S. Received October 24,—Read November 17, 1898.

(Abstract.)

1. *Object of the Investigation.*

No general consensus of opinion appears to exist as to the mode by which the metal of an alkali salt is liberated when the salt is vaporised

* Kuenen, ‘Phil. Mag.,’ 1897.